THE AGRONOMY GUIDE

2017–2018

PennState Extension

HOW TO USE THE GUIDE

The Penn State Agronomy Guide is designed for easy reading and quick reference. In Part 1: Crop and Soil Management, the chapters on specific crops include information about:

Varieties
Nutritional Requirements
Establishment
Harvesting
Special Considerations

In Part 2: Pest Management, the chapters on pest control for specific crops include sections on:

Weeds
Insects
Diseases

The College of Agricultural Sciences strongly recommends that you have a soil test made to determine your lime and fertilizer needs before using the suggestions presented throughout this book. Success is directly related to correct analysis of your soils.

This guide is not a substitute for the product label. Please consult a current product label for detailed usage information.

The Penn State Agronomy Guide was prepared by extension and resident staff members in the Departments of Agricultural and Biological Engineering; Agricultural Economics, Sociology, and Education; Ecosystem Science and Management; Entomology; Plant Pathology and Environmental Microbiology; and Plant Science representatives of the U.S. Pasture Laboratory; county agricultural extension educators; representatives of the fertilizer, lime, pesticide, and seed industries; and representatives of state agricultural and environmental government agencies.

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Part 2: Pest Management
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Part 1. Crop and Soil Management

Part 2. Pest Management

Average bushel weights and seed per pound

Average bushel weights and seed per pound for the major crops grown in Pennsylvania. This is presented as a guide for determining the amount of seed required to obtain a desired plant population. Seed per pound will vary from year to year depending on growing conditions.

Crop	*Bushel weight (lbs)*	*Average seed (lbs)*
Grain Crops		
Barley	48	13,600
Corn	56	1,450
Oat	32	12,700
Rye	56	18,080
Sorghum	56	14,000
Soybean	60	2,500
Sunflower, oilseed	27	6,000
Wheat	60	12,000

Crop	*Bushel weight (lbs)*	*Average seed (lbs)*
Forage Crops		
Alfalfa	60	220,000
Birdsfoot trefoil	60	1,000,000
Bromegrass	14	137,000
Fescue, tall	20	226,800
Ladino clover	60	860,000
Orchardgrass	14	590,000
Red clover	60	270,000
Reed canarygrass	46	550,000
Sudan grass	40	50,000
Timothy	45	1,230,000
Vetch, hairy	60	20,000

Useful weights and measures

1 acre	=	0.405 hectare
1 hectare	=	2.47 acres
1 acre	=	43,560 square feet
1 acre	=	4840 square yards
1 bushel (dry)	=	1.244 cubic feet
1 bushel (dry)	=	2,150 cubic inches
1 bushel (dry)	=	35.24 liters
1 bushel (dry)	=	4 pecks
1 bushel (dry)	=	32 quarts
1 cubic foot	=	0.804 bushel
1 cubic foot	=	25.714 quarts (dry)
1 cubic foot	=	29.922 quarts (liquid)
1 cubic foot	=	1728 cubic inches
1 cubic foot	=	7.48 gallons
1 cubic inch	=	16.39 cubic centimeters
1 cubic inch	=	0.554 ounces (fluid)
1 cubic yard	=	27 cubic feet
1 cubic yard	=	46,656 cubic inches
1 cubic yard	=	202 gallons
1 cubic yard	=	764.5 liters
1 gallon	=	3,785 cubic centimeters
1 gallon	=	231 cubic inches
1 gallon	=	0.1337 cubic feet
1 gallon	=	3.785 liters
1 gallon	=	128 fluid ounces
1 inch	=	2.54 centimeters
1 kilogram	=	35.274 ounces
1 kilogram	=	2.205 pounds
1 liter	=	33.81 ounces (fluid)
1 liter	=	1.816 pints (dry)
1 liter	=	2.11 pints (liquid)
1 liter	=	61.025 cubic inches
1 liter	=	0.264 gallons
1 meter	=	39.37 inches
1 mile	=	5,280 feet
1 mile	=	1,760 yards
1 mile per hour	=	1.467 feet per second
1 ounce (avoirdupois)	=	28.349 grams
1 ounce (fluid)	=	29.574 cubic centimeters
1 ounce (fluid)	=	1.805 cubic inches
1 pound	=	453.59 grams
1 pound	=	16 ounces
1 quart (dry)	=	67.20 cubic inches
1 quart (liquid)	=	57.75 cubic inches
1 rod	=	16.5 feet
1 rod	=	5.029 meters
1 rod	=	5.5 yards
1 square foot	=	144 square inches
1 square yard	=	9 square feet
1 ton (short)	=	907.185 kilograms
1 ton (short)	=	2,000 pounds
1 ton (long)	=	2,240 pounds
1 yard	=	91.440 centimeters
1 yard	=	3 feet

Conversion factors for English and metric units

All measurements in Part 2: Pest Management are reported in English units, e.g., lbs/A. However, you may have access to some data reported in metric units. If so, the conversions shown below may be of interest to you.

To convert column 1 into column 2, multiply by	*Column 1*	*Column 2*	*To convert column 2 into column 1, multiply by*
1.609	mile, mi	kilometer, km	0.621
0.914	yard, yd	meter, m	1.094
2.540	inch, in	centimeter, cm	0.394
2.590	mile^2, mi^2	kilometer^2, km^2	0.386
0.00405	acre, A	kilometer^2, km^2	247.1
0.405	acre, A	hectare, ha (0.01 km^2)	2.471
102.8	acre-inch	meter^3, m^3	0.00973
0.2852	cubic foot, ft^3	hectoliter, hl	3.532
0.352	bushel, bu	hectoliter, hl	2.838
0.946	quart (liquid), qt	liter, L	1.057
0.9072	ton (English), T	ton (metric), T	1.102
0.00454	pound, lb	quintal, q	220.5
0.454	pound, lb	kilogram, kg	2.205
2.242	ton (English)/acre	ton (metric)/hectare	0.446
1.121	lb/acre	kg/ha	0.892
1.121	hundredweight/acre	quintal/hectare	0.892
0.0703	lb/in^2, psi	kg/cm^2	14.22
0.06895	lb/in^2, psi	bar	14.50
1.013	atmosphere, atm*	bar	0.9869
1.033	atmosphere, atm*	kg/cm^2	0.9678
0.06805	lb/in^2, psi	atmosphere, atm*	14.70
0.555 (F-32)	Fahrenheit, F	Celsius, C	1.80C + 32
10.764	foot-candle, ft-c	lux	0.0929

*An “atmosphere” may be specified in metric or English units.

Soil Management

TABLES

FIGURES

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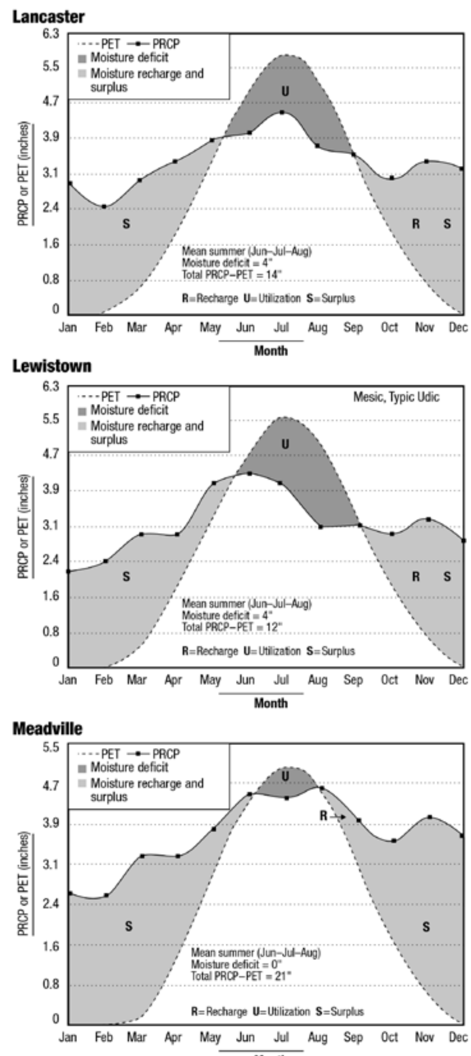
THE CLIMATE OF PENNSYLVANIA

Pennsylvania's climate is highly affected by movements of cold air masses descending from the north and subtropical air masses moving up from the south. Each spring the battle is on with frigid air causing temperatures to descend below freezing, alternating with periods when the mercury may rise above 80°F. Without large mountain ranges or water bodies surrounding the state, these air movements have fair play in the Commonwealth. Other large-scale processes that influence our climate are hurricanes developing east of the Caribbean that sweep across the Gulf of Mexico and subsequently move northeast. These air movements usually occur in the summer or early fall, pick up moisture above the oceans, and can dump large quantities of rain on parts of the state. While the movements of cold and warm air fronts determine temperature and precipitation from fall to spring, a different process governs normal precipitation patterns in the summer when convectional storms are common. Solar radiation warms the surface of the earth, causing air to rise. The relative humidity of the air increases as it cools, until moisture condenses and precipitation starts. This causes pockets of intense precipitation accompanied by thunderstorms in the summer. These events are highly localized, causing great variation in precipitation from one site to the next. The influence of the Great Lakes is also worth mentioning. Distinct zones are affected highly by air movements coming across Lake Erie. These air currents pick up moisture over the lake, causing bands of high snowfall in the winter. The lake also moderates the temperature near its shore. Temperature is also affected by elevation, which varies from 10 to 3,123 feet in Pennsylvania (the highest point is Mount Davis in Somerset County). Mountain ranges such as the Alleghenies cause orographic effects, with higher precipitation on the windward side and lower precipitation on the leeward side (Bedford, Franklin, Huntingdon counties). Overall, average precipitation in Pennsylvania varies from 32 to 49 inches per year. Average annual temperatures vary from 43 to 56°F, with higher temperatures in the southeast and coldest temperatures in the north-central parts of the state and at high altitudes. The frost-free period varies considerably, causing large variations in length of growing seasons. The latest hard frost in spring ranges from the end of March around Philadelphia and in pockets in Luzerne County to the beginning of June in sections of the Allegheny Plateau. The first hard frost begins typically around November in the southeast, but around September 1 at high elevations and northern parts of the state. The mean frost-free period is therefore only 100 days at high elevations in the Allegheny Mountains and on the Allegheny Plateau to almost 200 days in the southeast. The mean annual growing degree days (base 50) accumulated vary from approximately 1,800 to 3,600. The consequences for the types of crops grown in the different parts of the state are profound and cropping systems vary considerably.

Moisture stress is one of the major causes of yield variation in Pennsylvania. The differences in temperature and precipitation affect the water balance, which can be represented as P = E + T + R + D, where P = precipitation (snow and rain), E = evaporation (moisture loss from soil and plant surfaces), T = transpiration (moisture lost through leaves after uptake through roots), R = runoff, and D = deep drainage below root zone. Simulation models can help us estimate the moisture balance over the year. Let us ignore runoff and deep drainage for the moment and review how evaporation + transpiration (ET) and precipitation patterns vary in three contrasting locations in Pennsylvania (Figure 1.1-1). We will use the 1961–1990 climate data and employ the Newhall Simulation Model to calculate ET. Precipitation in Meadville, northwestern Pennsylvania, averages 44 inches, and annual potential ET is 24 inches, resulting in an annual moisture surplus of 21 inches. Moisture surplus is almost year-round, with a deficit of 0.3 inches in June/July. The last frost in this area is mid-May, while the first hard frost in the fall occurs early October. The growing season for summer crops is therefore approximately 4.5 months. Precipitation in Lewistown, central Pennsylvania, is 38 inches, and potential ET is 27 inches, with an annual moisture surplus of 11 inches. Moisture deficit from June to August is 3.7 inches. The last frost is in mid-April, and the first hard frost normally hits Lewistown in mid-October, giving it a growing season of about 6 months. In Lancaster, southeast Pennsylvania, precipitation averages 41 inches, and ET 27 inches, resulting in a moisture surplus of 14 inches. Moisture deficit from June to August is 3.8 inches. The last frost date in Lancaster is in mid-April, and the first hard frost late October, giving it a growing season of almost 6.5 months. Moisture deficits will clearly be a greater threat to crop production in the southeast than in the northwest, whereas the opposite can be expected of moisture surplus in the spring. How great the moisture challenges are in a particular location largely depends on the soil type, includes factors such as moisture storage capacity, depth to impervious layer, depth to water table and percolation, and are moderated by management practices.

Figure 1.1-1. Average moisture balance for Meadville (top), Lewisburg (middle), and Lancaster (bottom).



PRCP = monthly precipitation; PET = monthly potential evapotranspiration

Source: W. J. Waltman, E. J. Ciolkosz, M. J. Mausbach, M. D. Svoboda, D. A. Miller, and P. J. Kolb. *Soil Climate Regimes of Pennsylvania* (University Park: Penn State Agricultural Experiment Station, 1997).

THE SOILS OF PENNSYLVANIA

Twelve broad soil regions can be distinguished in Pennsylvania (Figure 1.1-2). They are described in the sections that follow. It will be clear that the primary determinant explaining differences between soils in Pennsylvania is the parent material from which the soils developed, with the effects of past glaciation also being important. Sedimentary rock is the origin of most soils in Pennsylvania, with some exceptions. Sandstone, shale, and limestone are the primary parent materials from which soils developed in the Commonwealth. The impact of past glaciers on soils is observed in northeastern and northwestern Pennsylvania.

1. Eastern Lake Shore

The soils on the shores of Lake Erie developed in beach sand and lacustrine silts and clays. The soils developed in the beach sands are mostly sandy and gravelly and have rapid internal drainage, although some have a shallow water table where the silts and clays underlie the beach deposits. The landscape is mostly level, and erosion potential is therefore low. The lacustrine soils generally contain few rock fragments and have moderate available water-holding capacity in the root zone. The climate is moderated by the proximity of Lake Erie.

2. Glaciated Region of the Appalachian Plateau

The soils in northwest Pennsylvania are derived from glacial till. Glacial till is a dense material that was once under huge masses of ice (glaciers). Water percolates very slowly through the till. Many soils in this region also have a fragipan—a dense subsoil that cannot be penetrated by roots and allows very slow water and air movement. The poor drainage of many soils in this region is characterized by gleying (gray color of reduced iron) and mottling (spots of gray color) caused by a perched seasonal high water table and impeded percolation.

The landscape is mostly level or undulating, and erosion potential is low to moderate. Rock fragments can be present if the till is near the soil surface. The available water-holding capacity of the root zone of these soils is primarily determined by the depth to the impermeable layer. If the soil is shallow, crop roots will have a small volume of soil to explore for water. The result is that crops may suffer drought stress in summer on soils that are saturated in spring. Although the growing season is short, the soils in this area can be highly productive if properly drained.

3. Allegheny High Plateau

Soils in the Allegheny High Plateau of northcentral Pennsylvania developed primarily in sandstone. The dominant texture of these soils is sandy loam. They are mostly well drained. If slopes are steep, erosion potential is substantial. Rock fragment content can be high. The available water-holding capacity of the root zone of these soils is often low due to their coarse texture and the presence of rock fragments. The growing season in this region is short (<100 days) because of the high elevation. Due to their low agricultural productivity, most soils of the Allegheny Plateau are under forest vegetation, but there are some notable exceptions, such as areas used for potato and pasture production.

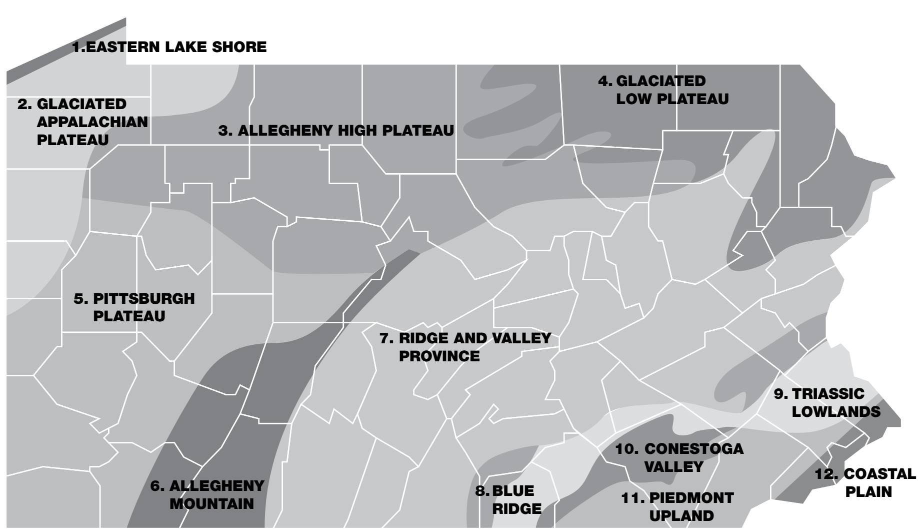
4. Glaciated Low Plateau

The soils in northeastern Pennsylvania are derived from glacial till like those in the northwestern part of the state. However, the till in the northeast is typically more discontinuous because the last glaciation occurred earlier in this area and the soils have had more opportunity to develop. Some of these soils have a fragipan at shallow depth and therefore are somewhat poorly to poorly drained. The surface texture of these soils is predominantly silt loam. The landscape is undulating and the erosion potential is low to moderate. Rock fragments are common in the soils of this area. Some of the soils have very low available water-holding capacity in the root zone due to their limited rooting depth. The growing season is short due to the elevation and northern latitude.

5. Pittsburgh Plateau

The Pittsburgh Plateau in central and southwest Pennsylvania is dominated by soils developed in acid clay shales and interbedded shales and sandstones. These soils contain more clay and silt than those derived from sandstone. The surface texture of these soils is predominantly silt loam. The soils are usually well drained. The landscape of this region has rather steep slopes, and erosion is a major concern. Many of these soils also contain substantial amounts of rock fragments. The root zone available water-holding capacity of many soils in this region is moderate due to their limited depth. However, in the southwest region of this area, soils tend to be deeper and have a moderately high root zone available water-holding capacity. The growing season is rather short in most of the area, with the exception of the southwest. Agriculturally, the most productive area is located in the southwest of this region.

Figure 1.1-2. Soil regions of Pennsylvania.



6. Allegheny Mountain

The Allegheny Mountain section is dominated by soils developed in sandstone. The texture is mostly sandy loam to loamy sand. Drainage is good. The landscape is often steeply sloping, and erosion potential is high. Rock fragments are common, resulting in low available water-holding capacity in the root zone. The high elevation of the Allegheny Mountain section gives this region a short growing season (<100 days). Much of this area is under forest vegetation, although there are some important agricultural areas.

7. Ridge and Valley Province

The ridges and valleys in the central/eastern part of Pennsylvania are a distinct landscape characterized by sandstone ridges, shale footslopes, and shale and limestone valleys. Sandy loam soils similar to those on the Allegheny High Plateau and Allegheny Mountain sections are found on the forested ridgetops. Colluvial soils that are a mixture of sandstone and shale are found on the slopes. In the valleys, limestone-derived soils predominate, although some are shale-derived. The limestone-derived soils are among the most productive in Pennsylvania. They are usually deep, well drained, have high available water-holding capacity in the root zone, and have few rock fragments. The shale-derived soils are less productive because of their acidic nature, steep slopes, and generally low available water-holding capacity in the root zone. The soils in the valleys are on level or undulating land, and erosion potential is low to moderate. The valley soils are used intensively for agriculture.

8. Blue Ridge

The Blue Ridge province covers eastern Franklin, southern Cumberland, and western Adams Counties. The soils in this area are derived primarily from igneous and metamorphic rocks. Igneous rocks are of volcanic origin. Metamorphic rocks have been altered under great pressure below the surface of the earth. The soils in these areas are generally well drained. Their surface texture is silt loam. They often contain significant amounts of rock fragments. Steep slopes are common, giving many soils in this area high erosion potential. The available water-holding capacity in the root zone of the soils is commonly moderate. The high elevation results in a short growing season. Much of this area is under forest.

9. Triassic Lowlands

The soils in the Triassic Lowland section of the Piedmont developed in reddish sandstone, shale, and siltstone. The soils are generally silt loams, well drained, and located on sloping land. The erosion potential of these soils is moderate to high. The Abbottstown-Doylestown-Reading association in Bucks and Montgomery Counties is an exception to this rule. The soils in that part of this region are poorly drained and are located on level land. The soils in the Triassic Lowland section can contain substantial amounts of rock fragments. The root zone available water-holding capacity of these soils is moderate. The region has a long growing season.

10. Conestoga Valley

Limestone-derived soils predominate in the Conestoga Valley section. These soils are comparable to the limestone soils in the valleys of the Ridge and Valley province. They have a silt loam surface texture and a clayey subsurface horizon. They are well drained. The landscape is level to undulating, and erosion potential is low. Rock fragments are scarce, and the available water-holding capacity in the root zone is high. The growing season is long. These are productive soils that are used intensively for agriculture.

11. Piedmont Upland

Soils in the Piedmont Upland section are predominantly derived from metamorphic rock. These soils have a silt loam texture and are well drained. The landscape has rather steep slopes, and erosion potential is moderately high. Rock fragments are scarce on these soils. Their water-holding capacity in the root zone is moderate to high. The growing season is long. These soils can be very productive if they are deep, and they are used intensively for agriculture.

12. Coastal Plain

The soils of the Coastal Plains section developed in coastal sands. These soils usually have a sandy surface texture and are well drained. Because the topography is level, erosion potential is typically low. The soils contain few rock fragments but have moderate available water capacity in the root zone due to the coarse soil texture. This region has the longest and warmest growing season of Pennsylvania. Most of the area is occupied by the city of Philadelphia and its suburbs.

Table 1.1-1 lists major soils of Pennsylvania, along with some of their properties and expected yield potentials.

SOIL HEALTH

Soil health (also called 'soil quality') is defined as "the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental health, and promote plant and animal health." Soil properties that determine soil health include soil physical, chemical, and biological properties. In this section we will focus on the physical and biological aspects of soil health (Box 1.1-1); chemical aspects are discussed in the soil fertility section. Some soil properties are a given and cannot be readily changed by management. This information can be gleaned from the county soil survey, as well as from your local USDA Natural Resources Conservation Service (NRCS) office or on the web at **websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx**.

Box 1.1-1. Key soil physical and biological properties.

- Soil texture
- Soil depth
- Soil organic matter content
- Cation exchange capacity
- Bulk density
- Porosity
- Plastic/liquid limit
- Soil structure and tilth
- Aggregate stability
- Water content
- Water-holding capacity
- Hydraulic conductivity (permeability)
- Infiltration rate
- Earthworms

Table 1.1-1. Selected properties and typical capabilities of major Pennsylvania soils.

Note: Ratings provide relative information for comparing soils and should not be used quantitatively.
Moisture contents: corn grain = 15.5%; corn silage = 65%; alfalfa and clover = dry matter; wheat, oats, and barley = 12%; sorghum/sudan = 65%; and soybeans = 13%

Soil series	*Depth class*[1]	*Drain class*[2]	*Leaching potential*[3]	*Crop prod. group*	*Corn grain (bu/A)*	*Corn silage (T/A)*	*Alfalfa (T/A)*	*Clover (T/A)*	*Wheat (bu/A)*	*Oats (bu/A)*	*Barley (bu/A)*	*Sorghum/sudan (T/A)*	*Soybeans (bu/A)*
Abbottstown	D[5]	SWPD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Albrights	D[5]	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Allegheny	D	WD	2	1	150	25	6	4	60	80	75	25	45
Allenwood	D	WD	2	1	150	25	6	4	60	80	75	25	45
Alton	D	WD[6]	3	3	125	21	4	3	50	60	50	21	30
Alvira	D[5]	SWPD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Andover	D[5]	PD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Armagh	D	PD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Atkins	D	PD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Barbour	D	WD	2[7]	1	150	25	6	4	60	80	75	25	45
Basher	D	MWD	2[7]	2	125	21	5	3.5	60	80	75	21	40
Bath	D[5]	WD	1[7]	2	125	21	5	3.5	60	80	75	21	40
Bedington	D	WD	2	1	150	25	6	4	60	80	75	25	45
Berks	MD	WD	2	3	125	21	4	3	50	60	50	21	30
Birdsall	D	PD	1[7]	5	100	17	3[8]	2	40[8]	60	40[8]	17	30
Birdsboro	D	MWD	2[7]	1	150	25	6	4	60	80	75	25	45
Blairton	MD	MWD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Bowmansville	D	SWPD	2[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Braceville	D[5]	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Brecknock	D	WD	2	2	125	21	5	3.5	60	80	75	21	40
Brinkerton	D	PD	2	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Brooke	MD	WD	1	2	125	21	5	3.5	60	80	75	21	40
Buchanan	D[5]	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Bucks	D	WD	2	1	150	25	6	4	60	80	75	25	45
Calvin	MD	WD	2	3	125	21	4	3	50	60	50	21	30
Cambridge	D[5]	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Canfield	D[5]	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Cavode	D	SWPD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Chenango	D	WD[6]	3	2	125	21	5	3.5	60	80	75	21	40
Chester	D	WD	2	1	150	25	6	4	60	80	75	25	45
Chippewa	D[5]	PD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Clarksburg	D[5]	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Clymer	D	WD	2	2	125	21	5	3.5	60	80	75	21	40
Comly	D	SWPD	1[7]	3	125	21	4[8]	3	50	60	50	21	30
Conestoga	D	WD	2	1	150	25	6	4	60	80	75	25	45
Conotton	D	WD	2	2	125	21	5	3.5	60	80	75	21	40
Cookport	D[5]	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Croton	D[5]	PD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Culleoka	MD	WD	2	3	125	21	4	3	50	60	50	21	30
DeKalb	MD	WD	2	3	125	21	4	3	50	60	50	21	30
Dormont	D	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Duffield	D	WD	2	1	150	25	6	4	60	80	75	25	45
Duncannon	D	WD	2	1	150	25	6	4	60	80	75	25	45
Edgemont	D	WD	2	2	125	21	5	3.5	60	80	75	21	40
Edom	D	WD	1	2	125	21	5	3.5	60	80	75	21	40
Elliber	D	WD[6]	3	2	125	21	5	3.5	60	80	75	21	40
Erie	D[4]	SWPD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Ernest	D[5]	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Fredon	D	SWPD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Frenchtown	D[5]	PD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Gilpin	MD	WD	2	3	125	21	4	3	50	60	50	21	30
Glenelg	D	WD	2	1	150	25	6	4	60	80	75	25	45
Glenville	D[5]	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Guernsey	D	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Hagerstown	D	WD	1	1	150	25	6	4	60	80	75	25	45
Hanover	D[5]	WD	1[7]	2	125	21	5	3.5	60	80	75	21	40
Hartleton	D	WD	2	3	125	21	4	3	50	60	50	21	30
Hazelton	D	WD	2	2	125	21	5	3.5	60	80	75	21	40
Highfield	D	WD	2	1	150	25	6	4	60	80	75	25	45
Holly	D	PD	2[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30

(continued)

Table 1.1-1. Selected properties and typical capabilities of major Pennsylvania soils (continued).

Soil series	*Depth class*[1]	*Drain class*[2]	*Leaching potential*[3]	*Crop prod. group*	*Corn grain (bu/A)*	*Corn silage (T/A)*	*Alfalfa (T/A)*	*Clover (T/A)*	*Wheat (bu/A)*	*Oats (bu/A)*	*Barley (bu/A)*	*Sorghum/sudan (T/A)*	*Soybeans (bu/A)*
Hublersburg	D	WD	2	1	150	25	6	4	60	80	75	25	45
Huntington	D	WD	2	1	150	25	6	4	60	80	75	25	45
Klinesville	S	WD	2	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Kreamer	D	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Lackawanna	D[5]	WD	1[7]	2	125	21	5	3.5	60	80	75	21	40
Laidig	D[5]	WD	1[7]	2	125	21	5	3.5	60	80	75	21	40
Langford	D[5]	WD	1[7]	3	125	21	4	3	50	60	50	21	30
Lansdale	D	WD	2	2	125	21	5	3.5	60	80	75	21	40
Leck Kill	D	WD	2	2	125	21	5	3.5	60	80	75	21	40
Lehigh	D	MWD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Letort	D	WD	2	1	150	25	6	4	60	80	75	25	45
Lewisberry	D	WD	2	2	125	21	5	3.5	60	80	75	21	40
Lordstown	MD	WD	2	3	125	21	4	3	50	60	50	21	30
Manor	D	WD	2	2	125	21	5	3.5	60	80	75	21	40
Mardin	D[5]	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Meckesville	D[5]	WD	1[7]	2	125	21	5	3.5	60	80	75	21	40
Melvin	D	PD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Mertz	D	WD	1	2	125	21	5	3.5	60	80	75	21	40
Monongahela	D[5]	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Morris	D[4]	SWPD	2	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Morrison	D	WD	2	2	125	21	5	3.5	60	80	75	21	40
Murrill	D	WD	2	1	150	25	6	4	60	80	75	25	45
Neshaminy	D	WD	2	1	150	25	6	4	60	80	75	25	45
Opequon	S	WD	2	4	100	17	4[8]	2.5	40	60	40	17	30
Oquaga	MD	WD	2	3	125	21	4	3	50	60	50	21	30
Penn	MD	WD	2	3	125	21	4	3	50	60	50	21	30
Philo	D	MWD	2[7]	2	125	21	5	3.5	60	80	75	21	40
Platea	D[5]	SWPD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Pope	D	WD	2	1	150	25	6	4	60	80	75	25	45
Rainsboro	D	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Ravenna	D[5]	SWPD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Rayne	D	WD	2	1	150	25	6	4	60	80	75	25	45
Readington	D[5]	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Reaville	D	SWPD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Red Hook	D	SWPD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Sheffield	D[5]	PD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Shelmadine	D[5]	PD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Swartswood	D[5]	MWD	1[7]	2	125	21	5	3.5	60	80	75	21	40
Tunkhannock	D	WD[6]	3	2	125	21	5	3.5	60	80	75	21	40
Tyler	D	SWPD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Upshur	D	WD	1	2	125	21	5	3.5	60	80	75	21	40
Venango	D[5]	SWPD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Volusia	D	SWPD	1[7]	4	100	17	4[8]	2.5	40[8]	60	40[8]	17	30
Washington	D	WD	2	1	150	25	6	4	60	80	75	25	45
Watson	D[5]	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Weikert	S	WD[6]	2	4	100	17	4[8]	2.5	40	60	40	17	30
Wellsboro	D[5]	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Westmoreland	D	WD	2	2	125	21	5	3.5	60	80	75	21	40
Wharton	D	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Wheeling	D	WD	2	1	150	25	6	4	60	80	75	25	45
Wurtsboro	D[5]	MWD	1[7]	3	125	21	4	3	50	60	50	21	30
Wyoming	D	WD[6]	3	3	125	21	4	3	50	60	50	21	30

1. Depth classes: D = deep (>40 inches); MD = moderately deep (20 to 40 inches); S = shallow (<20 inches)
2. Drainage classes: WD = well drained; MWD = moderately well drained; SWPD = somewhat poorly drained; PD = poorly drained
3. Leaching ratings—these are only a relative rating of leaching potential. The higher the number, the greater the relative leaching potential.
4. A fragipan is present at 10 to 16 inches (0.25 to 0.40 meters) below the surface of the soil.
5. A fragipan is present at 16 to 40 inches (0.40 to 1 meter) below the surface.
6. These soils are well drained to excessively well drained.
7. These soils have a seasonal high water table that is less than 6 feet from the surface. Leaching potential may be a consideration of water resource use and water table following pesticide application.
8. Crop is not well suited for this soil.

However, the concept of soil health focuses on those properties that are readily affected by management. The best soil quality is usually found in soils under permanent vegetation such as trees or sod. Intensively managed soils, on the other hand, can have very low or very high soil quality depending on how they are managed. Soils with poor health often have inferior tilth, lower organic matter content, few living organisms, and show signs of soil erosion, crusting, and soil compaction. Eventually, poor soil health results in problems with crop establishment, root growth, and crop yields. Increasing amounts of fertilizers, pesticides, and tillage are needed to maintain yields on poor-quality soil. That is why it is so important to maintain high soil quality. We will now discuss some important soil properties that determine soil health.

Soil texture is a classification of the primary particle size distribution of soil that has a profound effect on other soil health indicators such as porosity, water infiltration and percolation, moisture-holding capacity, and sensitivity to compaction. The textural class is a measure of the proportions of sand (2.00–0.05 mm diameter), silt (0.05–0.002 mm), and clay (smaller than 0.002 mm) (Figure 1.1-3). Only particles smaller than 2 mm (0.79 inch) are considered when classifying soil texture, so gravel and rocks are not included in soil texture classifications. Soil texture is determined in the laboratory after completely dispersing soil aggregates with a deflocculant. With experience, it is also possible to determine soil texture by the "feel method." Soil textural class mentioned with soil series name (e.g., Hagerstown silt loam) refers to the soil texture of the surface soil and does not take into account differences in clay content in the subsoil, impermeable layers near the surface, rock fragments, and so forth.

Soil depth is the depth of soil to bedrock or to an impermeable layer. Soil depth determines how deep roots, water, and air can penetrate into a soil. This, in turn, influences how much water can infiltrate the soil, how much water can be held by the soil, and how much soil plant roots can occupy.

Soil organic matter consists of living and partially to fully decomposed organic materials. Soil organic matter is typically 1 to 5 percent of the total dry weight of topsoil, with lower amounts in the subsoil. Different types of organic matter play unique roles in soil. Highly decomposed organic matter (also called humified organic matter) typically makes up 95 percent of the total soil organic matter and contributes to the cation exchange capacity, the water-holding capacity, and stability of small aggregates. Other, less highly decomposed types of organic matter, such as polysaccharides, are produced by bacteria and determine the stability of larger aggregates. Living organic matter, such as fungal hairs and plant roots, are also important for the stability of large aggregates.

The *CEC (cation exchange capacity)* of a soil is determined by the soil's clay and humus content. These particles carry a negative charge that enables a soil to hold positively charged molecules (cations). Potassium, calcium, and magnesium are nutrient cations that dissolve in water and would wash out of the soil if they were not held by the CEC. The CEC of your soil is reported on soil test reports.

Bulk density is a measure of the mass of particles that are packed into a volume (e.g., a cubic foot) of soil. If bulk density goes up, porosity goes down. It is favorable to have a low bulk density so that water and air can move through the soil. The optimal bulk density depends on soil texture. Ideal and problem bulk densities of different soils are given in Table 1.1-2.

The *plastic and liquid limits* of a soil are two measures used to characterize the ease with which a soil can be worked or compacted. The plastic limit is the moisture content at which it is possible to make a wire of approximately one-quarter inch in diameter by rolling the soil between your hands. The liquid limit is the moisture content at which soil starts to flow and act like a liquid. Soil is most compactable between the plastic and liquid limit and most susceptible to rutting above the liquid limit. A simple method to determine soil readiness for tillage and traffic is the "ball test." Take a handful of soil and squeeze it into a ball. If the soil molds together, it is in the plastic state and too wet for planting, tillage, or field traffic.

Figure 1.1-3. The textural triangle quickly helps to determine the textural classification of a soil from the percentages of sand, silt, and clay it contains.

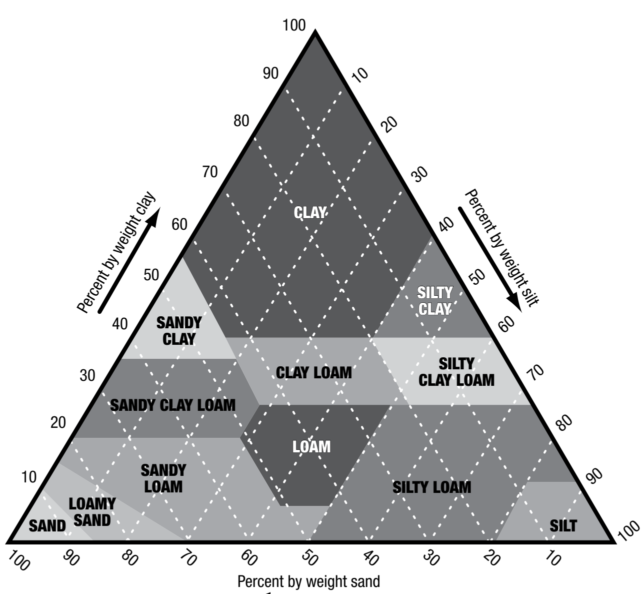


Table 1.1-2. Ideal soil bulk densities and root growth limiting bulk densities for soils of different textures.

Soil texture	Ideal bulk densities	Bulk densities that may affect root growth	Bulk densities that may restrict root growth
		(g/cm^3)	
Sand, loamy sand	<1.60	1.70	>1.80
Sandy loam, loam, sandy clay loam, clay loam, silt, silt loam, silty clay loam	<1.40	1.60	>1.75
Sandy clay, silty clay, clay	<1.10	1.50	>1.60

Source: Generalized from USDA-NRCS soil quality test kit guide.

Soil structure and *soil tilth* are very important but still elusive concepts. Soil tilth refers to the state of aggregation of a soil. *Aggregates* are conglomerates of clay, silt, and sand particles that are held together by biological, physical, and chemical forces. A common method of determining aggregate stability is to place aggregates on a sieve and move the sieve up and down in a water bath. If a lot of soil passes through the sieve, the aggregate stability is low; if most of the soil remains on top of the sieve, the aggregate stability is high. Soils with stable aggregation tend to have better soil tilth, greater water infiltration, and better aeration for crop growth.

Hydraulic conductivity (permeability) and *infiltration rate* are two closely related properties. Hydraulic conductivity is the rate of water movement in the soil, whereas infiltration is the rate at which water enters into the soil from the surface. Hydraulic conductivity and infiltration are determined by soil texture, changes in soil texture between surface and subsurface, impermeable layers, and depth to bedrock, as well as by soil management.

Earthworms generally increase microbial activity, increase the availability of nutrients, and enhance soil physical properties. They also accelerate the decomposition of crop residue by incorporating litter into the soil and activating mineralization and humification processes. Earthworms improve aggregation and porosity, suppress certain pests or disease organisms, and enhance beneficial microorganisms. There are different types of earthworms; some live in the surface of the soil and make horizontal burrows, while others live in the vertical burrows that can be more than 3 feet deep. Some earthworms make permanent burrows, while other earthworms fill their burrows with excretions. Nightcrawlers are among the important earthworm species in agricultural soils. They make permanent, vertical burrows that provide channels for infiltration. They need surface residue, which they gather and deposit on top of their burrows. A good method to monitor earthworm populations is to excavate one cubic foot (1 x 1 x 1 ft) of soil and count the earthworms in and beneath it. A good time to do this is after a rainstorm or early in the morning in spring or fall when the soil is moist. Earthworms tend to hide deeper when the soil is dry and show reduced activity in summer or winter. Earthworms that reside below the foot-deep hole will come to the surface if you pour some mustard powder dissolved in water in the hole. Ten earthworms per square foot of soil surface is generally considered a good population in agricultural systems.

Measuring soil health with scientific methods takes major investments. Therefore, Penn State developed the *Pennsylvania Soil Quality Assessment Scorecard*, available from your Penn State Extension county office or online at **extension.psu.edu/publications/uc170/view**.

Improving Soil Health

Soil Organic Matter

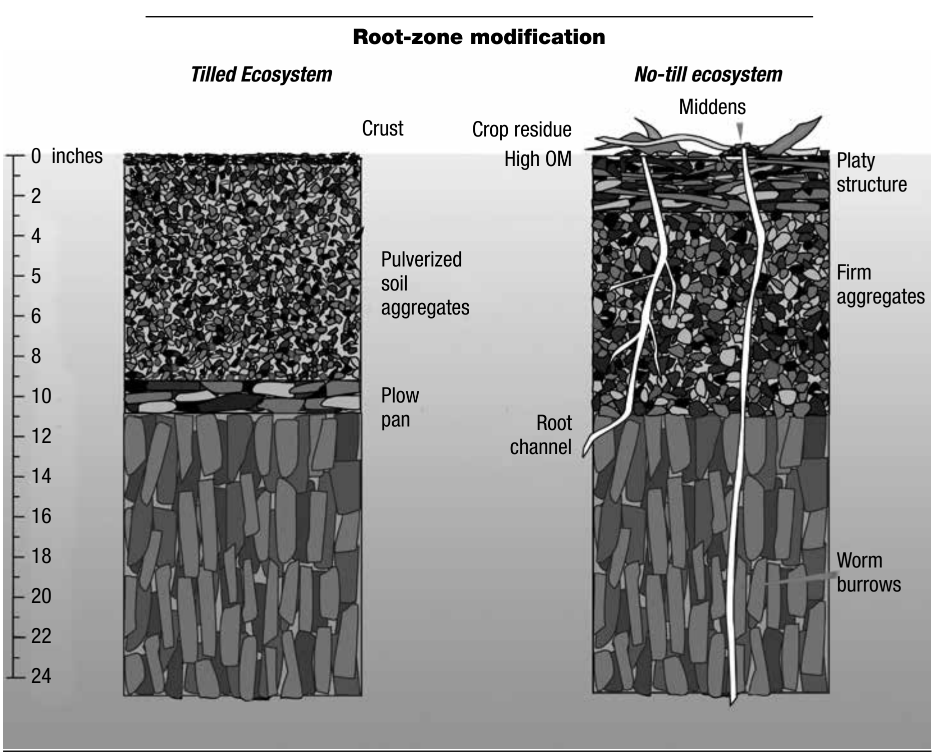
Soil organic matter content is considered one of the most important indicators of soil health. From an agronomic and environmental point of view, organic matter gives the largest benefits if it is found close to the soil surface. Near-surface organic matter improves soil aggregation, which increases infiltration, improves resistance to erosion, improves workability, and leads to improved seed-to-soil contact when planting. The surface soil also becomes more resistant to compaction and will facilitate root development. To maintain or increase near-surface organic matter content, one needs to maximize inputs, or additions, of organic materials and minimize outputs, or losses. Inputs can be increased by growing crops that produce large amounts of residue and fine roots (species such as corn, small grains, grasses), leaving crop residue in the field, growing cover crops during otherwise bare fallow periods, and adding compost and manure (especially bedded manure). How much organic material should be returned to the soil to maintain organic matter contents? This question has been receiving increased attention because of the interest in harvesting crop residue to produce biofuels. A recent review suggests that in a no-till system, 4,500 lbs/A of crop residues need to be returned per year to maintain surface organic matter content under conditions pertaining to the Corn Belt. To meet this goal will be very challenging because most annual crops don't produce that much crop residue, even without residue removal (Table 1.1-3). Other sources of organic inputs are manure, compost, and cover crops. Liquid manure does not contribute to organic matter if it does not contain any solids. Highly decomposed packed manure or compost contributes much to organic matter content since it is already partly humified. Organic matter losses include removal of crop residue (such as hay, straw, or silage harvest) and burning. Soil tillage reduces surface organic matter content, so eliminating tillage will help improve soil health. The type of tillage also matters; the moldboard plow tends to cause the largest losses of surface organic matter, while the chisel plow and disk har-

Table 1.1-3. Crop residue production of different crops in rotation.

	Yield (bu/A)	Bushel weight (lbs/bu)	Yield (lbs/A)	Moisture content (ratio)	Dry matter (ratio)	Grain dry matter yield (lbs/A)	Residue:grain ratio	Residue dry matter yield (lbs DM/A)	Tons/A
Barley	70	48	3,360	0.120	0.880	2,957	1.5	4,435	2.2
Corn	130	56	7,280	0.155	0.845	6,152	1.0	6,152	3.1
Oats	60	32	1,920	0.120	0.880	1,690	1.0	1,690	0.8
Rye	50	56	2,800	0.120	0.880	2,464	1.5	3,696	1.8
Sorghum	90	56	5,040	0.135	0.865	4,360	1.5	6,539	3.3
Soybeans	40	60	2,400	0.130	0.870	2,088	1.0	2,088	1.0
Wheat	55	60	3,300	0.120	0.880	2,904	1.5	4,356	2.2

To calculate crop residue yield, multiply crop grain yield (bu/A) by bushel weight (lbs/bu) and dry matter content (ratio) and residue:grain ratio.

Figure 1.1-4. No-till soil-profile changes compared to changes in a tilled-soil profile.



row cause smaller surface organic matter losses. Recent research suggests that tillage primarily redistributes organic matter to deeper soil layers. With moldboard plowing, soil organic matter content is uniform throughout the plow layer. In long-term no-tillage or sod, on the other hand, soil organic matter content will be high at the soil surface and decrease rapidly below 2 or 3 inches. Chisel plows and disks tend to lead to soil organic matter distribution that is intermediate between moldboard and no-tillage.

Aggregate Stability or Soil Tilth

Besides organic matter, crop rotations and crop mixtures can help improve the aggregation of soils. When designing crop rotations, take the following factors in account: (1) crops with extensive, fine root systems, such as grasses and cereals, stimulate aggregate stability; (2) perennial crops in the rotation have a favorable effect on aggregation that lasts many years; and (3) actively growing root systems improve soil aggregation. Crops with easily decomposed residue (C:N ratio below 25) stimulate aggregate stability in the short term because bacteria that feast on the residue produce polysaccharides and other easily degradable organic substances that act as glue holding aggregates together. Amendments (such as manure or sewage sludge) that stimulate biological activity will also help improve aggregate stability.

Soil Profile Modification

The soil profile is modified by tillage (Figure 1.1-4). Tillage mixes soil and crop residues in the surface, pulverizes aggregates, increases soil sealing and crusting at the very surface of the soil, compacts soil just below the tillage tool, and leads to a decline in certain earthworm species, especially nightcrawlers, that make deep burrows into the subsoil. In long-term no-till, on the other hand, the soil profile is characterized by mulch cover that protects the soil from the elements and provides a food source and habitat for soil organisms, high organic matter content near the surface that decreases rather abruptly with depth, macropores (many created by nightcrawlers) that lead from the surface 3 to 4 feet into the soil, and a firm soil that has intact aggregates. The changed soil profile in long-term no-till leads to higher infiltration and reduced evaporation and makes the soil more trafficable. It should be noted that the soil-profile modification needs time to develop but can be changed rapidly by one tillage pass—hence the importance of long-term no-tillage.

SOIL EROSION

Soil erosion is the most important soil degradation problem in Pennsylvania. It contributes to the loss of soil quality and pollution of surface waters. Soil erosion above a certain level will reduce soil productivity over the long haul. Soil erosion exposes subsoil, which has often poor qualities for crop establishment and growth. It can also lead to stand loss by sediment deposition. Three types of soil erosion are classified as water erosion, wind erosion, and tillage erosion. Water and tillage erosion are the more important types of erosion in Pennsylvania and will be discussed here. A survey by USDA-NRCS revealed that 60 percent of the cropland in Pennsylvania is "highly erodible land" (HEL). In 2003, 40 percent of the HEL cropland eroded at greater than tolerable levels. Eleven percent of non-HEL cropland eroded above the tolerable level. In summary, more than one-quarter of cropland in Pennsylvania is losing soil at a rate that affects soil productivity in the long run.

WATER EROSION

The four types of water erosion are as follows:

1. Inter-rill erosion—the movement of soil by rain splash and its transport by thin surface flow.
2. Rill erosion—erosion by concentrated flow in small rivulets.
3. Gully erosion—erosion by runoff scouring large channels (deeper than 1 foot).
4. Streambank erosion—erosion by rivers or streams cutting into banks.

The term "sheet erosion" is still frequently used, but omits the concept of rainsplash and conveys the erroneous concept that runoff commonly occurs as a uniform sheet. Since soil management affects inter-rill and rill erosion, we will focus on these in the following discussion.

The threat of inter-rill and rill erosion is affected by the amount and intensity of rainfall, the erodibility of the soil, the slope length and steepness, cropping and management factors, and erosion control practices. The USDA-NRCS uses book values for erosivity and erodibility and combines this with field observations and farmer information about management practices to estimate the average annual soil loss of a field.

The USDA-NRCS uses the Revised Universal Soil Loss Equation (RUSLE) to calculate soil loss by erosion as a function of five factors:

$A = R \times K \times LS \times C \times P$

Where:

A = annual soil loss (tons/a/yr)

R = erosivity of rainfall (function of total rainfall and rainfall intensity)

K = erodibility of the soil (function of soil texture, soil organic matter, and soil structure)

LS = slope length/steepness

C = cropping and management factors (e.g., crops grown, canopy cover, residue cover, surface roughness)

P = erosion control practices (contour tillage and planting, strip-cropping, terracing, subsurface drainage)

The impact of raindrops on the soil surface is the beginning, and most important part, of the erosion process. The extent of erosion caused by rainfall (erosivity) depends on the size and velocity of raindrops and the amount of precipitation. Gentle, drizzly rain is not very erosive, whereas fierce thunderstorms and hurricanes are very erosive. High-intensity storms produce larger drops that fall faster than those of low-intensity storms and therefore have greater potential to destroy aggregates and dislodge particles from the soil matrix. Although the same total amount of rain may fall, a short, high-intensity rainfall event causes much more erosion than a long, low-intensity storm. Total average precipitation does not vary much across Pennsylvania, but the intensity of rainfall does. Thunderstorms and hurricanes with accompanying high-intensity rainfall tend to hit the southeastern part of the Commonwealth more frequently, leading to a higher erosion threat in the southern rather than northern parts of Pennsylvania. Most erosive precipitation events usually occur in the late summer and early fall. Soils that are bare during this period are under extreme risk of soil erosion. Bare soil (especially if planted to wide-spaced crops such as corn) is also extremely vulnerable to erosion before canopy closure in the spring.

Soils differ in their susceptibility to erosion (erodibility) depending on natural and human factors. Erodibility is influenced by many factors, some of which vary during the year and/or vary with soil management:

- Erodibility of a soil increases with a decrease in aggregate stability. Clay and organic matter help improve aggregate stability and reduce erodibility.
- Living or dead roots increase aggregate stability and decrease erodibility.
- Erodibility decreases with an increase of large sand grains and rock fragments because these large particles are not easily moved with water.

Soil conservation personnel use standard erodibility values published for each soil series in their county based on typical soil texture, structure, and organic matter contents.

Since soils are continuously formed from parent material, it is commonly accepted that a low level of erosion will not compromise soil productivity. NRCS personnel use tolerable soil loss levels (T), which vary per soil type, to indicate the maximum rate of soil erosion that can be allowed while still permitting crop productivity to be sustained indefinitely. Levels of T are a function of root development, gully prevention, on-field sediment problems, seeding losses, reduction of soil organic matter, and loss of plant nutrients. The level of T varies from 3 to 5 tons per acre per year for most soils in Pennsylvania. Deep soils with subsoil characteristics favorable for plant growth have greater T levels than soils with shallow root zones or high percentages of shale at the surface. The reason is that the shallow soils and soils with high contents of rock fragments lose their productivity more quickly than deep soils without rocks fragments.

The two types of water erosion that can be controlled by soil management practices are inter-rill and rill erosion. Engineering structures such as grassed waterways and streambank reinforcement help control other types of water erosion.

Cropping and management practices used to control erosion include previous management and cropping, the protection of vegetative canopy to the soil surface, and surface cover and roughness. Generally, the following most important crop management practices will help decrease water erosion:

- Maintain crop residue cover above 30 percent until crop canopy closure.
- Alternate summer crops with winter crops and perennial crops.
- Use cover crops during periods when the soil would have insufficient residue.

Additional protection from water erosion is provided by contour farming and contour strip-cropping. *Contour farming* implies that crops are planted nearly on the contour. The benefit of this practice is greatest on moderate slopes (2 to 6 percent) when crops are planted in tilled soil where ridge height is 2 to 3 inches. However, even in no-till contour farming can reduce erosion if residue cover is marginal and ridge height is 2 inches or more.

Contour strip-cropping involves alternating strips of perennial grass or close-growing crops with strips with low residue cover. The strips should be laid out close to the contour, which is not always possible in rolling landscapes. Strip width is usually between 75 and 120 feet. Soil that erodes from the bare or low-residue strips is deposited in strips with high residue or dense vegetation because runoff velocity is decreased. This practice is most useful if the soil is tilled, or if the soil is left bare during part of the year in no-till. In today's cropping systems the difference in cover between strips is frequently minimal, which reduces the effectiveness of this practice. If high-residue cover (greater than 30 percent at all times) is maintained in no-till systems, contour farming and contour strip-cropping are usually not necessary to control erosion.

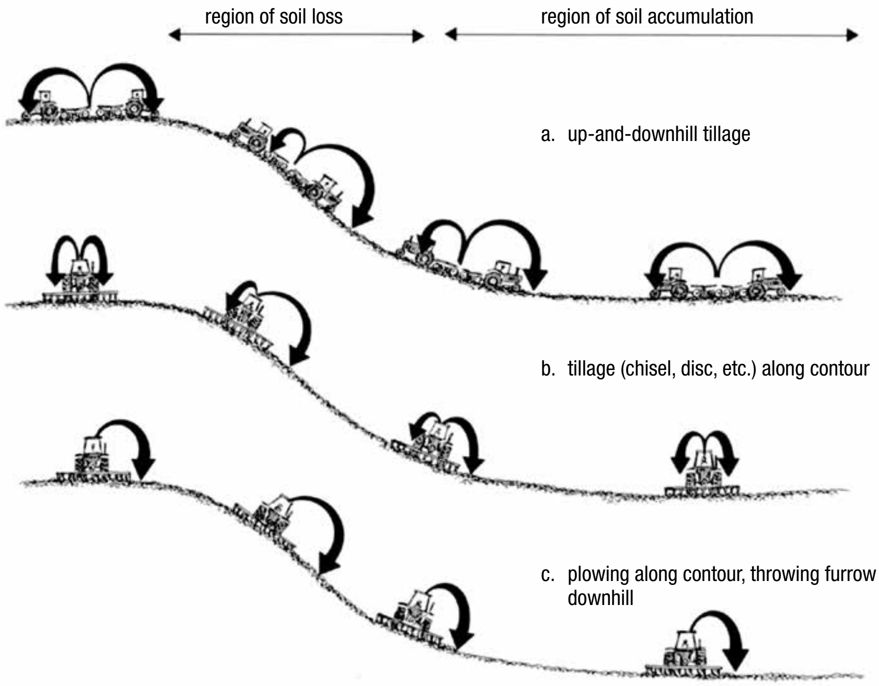
As slope length and steepness increase, runoff and soil loss also increase. Changing slope steepness with management practices is relatively uncommon in Pennsylvania. Slope length can be changed by installing terraces and diversions that divert runoff.

Terraces are cross-slope channels that control erosion on cropland and are built so that crops can be grown on them. Storage terraces hold water until it can be absorbed by the soil or released to stable outlet channels or through underground outlets. Storage terraces are usually designed to drain completely in 48 hours to avoid waterlogging within the terrace. Gradient terraces are channels designed almost perpendicular to the natural field slope that collect runoff water and carry it to a stable outlet like a waterway.

Diversions are similar to terraces, except that they are permanently vegetated with grass. They are used on steeper slopes where a terrace would be too expensive or difficult to build, maintain, or farm. They can also be used to protect barnyards or farmsteads from runoff.

Other erosion-control practices help maintain water quality but are not imme-

Figure 1.1-5. Three causes of erosion resulting from tilling soils on slopes.



Source: Fred Magdoff and Harold van Es, *Building Soils for Better Crops*, 2nd ed. (Beltsville, Md.: Sustainable Agriculture Network, 2000), 47. Used with permission from the Sustainable Agricultural Research and Education (SARE) outreach office, www.sare.org.

diately relevant to maintain soil productivity on working cropland. The following practices are helpful in reducing sediment and nutrient load in surface waters even though they do not directly improve soil quality:

- *Contour buffer strips*—permanently vegetated strips located between larger crop strips on sloping land.
- *Field borders*—bands or strips of permanent vegetation at the edge of a field.
- *Filter strips*—strips or areas of permanent vegetation used to remove sediment, organic materials, nutrients, pesticides, and other contaminants from runoff.
- *Riparian forest buffers*—areas of trees and/or shrubs along streams, lakes, ponds, or wetlands.
- *Vegetative barriers*—narrow permanent strips of stiff-stemmed, tall, dense perennial vegetation established in parallel rows perpendicular to the dominant field slope.
- *Grassed waterways*—natural or constructed swales where water usually concentrates as it runs off a field.
- *Streambank protection*—structures such as fences and stable crossings to keep livestock out of the streams as well as streambank stabilization with rocks, grass, trees, shrubs, riprap, or gabions.

TILLAGE EROSION

Tillage erosion is a form of erosion that is receiving increased attention. Tillage erosion moves soil from the top of the field downward, exposing subsoil at the crest while burying soil at the bottom. After many years of tillage, topsoil accumulates at the bottom of the slope. If tillage erosion continues, exposed and eroded subsoil from upslope will eventually cover this topsoil at the bottom of the slope. With tillage erosion, no soil has to leave the field, but the effects for productivity and increased yield variability can be very significant. Exposed subsoil has unfavorable properties for crop growth (50 percent yield reduction is not uncommon on clay knobs), but it still takes the same amount of inputs such as seed, fertilizer, and herbicides. Because crop growth is poor, the soil is not protected from water erosion, and weeds have a greater chance to become a problem in these areas. Tillage erosion delivers soil from upper slope positions to the lower parts of the slope where water erosion tends to be more important, so tillage erosion tends to reinforce water erosion (Figure 1.1-5).

Unfortunately, many practices that have been promoted to control water erosion do nothing to control tillage erosion. For example, it is suggested that chisel plows cause as much tillage erosion as moldboard plows. Field cultivators can also move substantial amounts of soil. Leaving crop residue at the surface does not control tillage erosion. Narrow contour strips, often promoted on steep slopes to control water erosion, favor tillage erosion because at the top of each strip topsoil is slowly plowed away, exposing subsoil, while soil accumulates at the bottom of each strip. The narrower the strips, the more subsoil can be exposed.

The best solution to control tillage erosion is to eliminate tillage. With the use of continuous no-till systems, tillage erosion can be completely eliminated. If tillage is still part of the crop production system, all unnecessary tillage trips should be eliminated, speed reduced (especially downhill), and tillage tools set to the shallowest depth possible. Down-hill plowing should be avoided. Plowing on the contour causes less tillage erosion, whereas plowing uphill causes the least (although it doesn't totally eliminate tillage erosion like no-till). It is beneficial to turn soil uphill with contour tillage, but this is practically impossible if slopes exceed 17 percent. Running the tillage tool at constant depth and speed is recommended to limit tillage erosion (so don't reduce tillage depth or slow down on clay knobs or rock outcroppings). This often means additional horsepower is required to pull the tillage tool, which can result in damage to tillage equipment. The final solution to "solve" tillage erosion is to transport topsoil from depositional areas to hill crests to remediate clay knobs and rock outcroppings.

SOIL COMPACTION

Soil compaction is the reduction of soil volume due to external factors. The risk of soil compaction is greater today than in the past due to an increase in the size of farm equipment.

Soil compaction reduces soil productivity. Research in tilled soils showed average first-year yield losses due to severe compaction of approximately 15 percent. Yield loss in the first year after compaction was mostly due to residual effects of surface compaction. In this summary of many studies in different countries, yield losses decreased to approximately 3 per-